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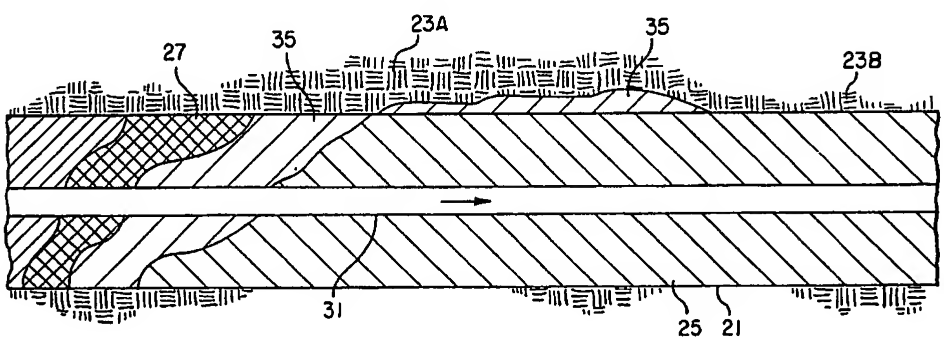

(57) Abstract

A method of cementing a well penetrating a subterranean formation and having a deviated section (21) of more than 55 degrees angle of inclination in which a plurality of cement slurries (25, 35) are employed, at least one of which is less dense than the drilling fluid employed to drill the well, and allowing the cement to set up in the well and to bond in situ and provide zonal isolation and good bonding of equipment in the wellbore. The cement slurry may include micro-spheres of fly ash or borosilicate to reduce free water voids of channels in the cement.

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CEMENT SLURRIES FOR DEVIATED WELLS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to cement slurries that enhance displacement efficiency and zonal isolation in subsurface or subterranean cementing in oil field applications.

Description of the Prior Art

The prior art is replete with many disclosures of cementing in wells penetrating subterranean formations, as in oil field technology. Typically, when cementing a well, a cement spacer fluid and then one or more cement slurries are employed to displace/replace drilling fluid from an area of the wellbore and secure hydraulic zonal isolation across the cemented interval. However, poor or inefficient displacement of the drilling fluid remains one of the primary problems encountered in achieving effective hydraulic isolation.

The problem of cementing in wellbores penetrating subterranean formations is intensified when a portion of the wellbore, for example, up to several thousand feet, is deviated, or in a substantial degree departs from the vertical orientation that is normally effected when drilling to the desired depth in subterranean formations.

There are several published papers and patents that address the problem of deviated wellbore cementing. Of these, the following are included:

U.S. Patent No. 5,027,900, "Incremental Density Cementing Spacers", W. N. Wilson, July 2, 1991.

SPE 16928 "A Laboratory Investigation of Cementing Horizontal Wells"; M.A. Wilson and F.L. Sabina of Halliburton, Copyright 1983; and

"Guides Emerge for Cementing Horizontal Strings", Phillippe Parcevaux, Technology Section pages 35-41, October 19, 1987, Oil and Gas Journal.

These past studies have shown that as the angle of inclination increases, so does the incidence and extent of annular communication problems. Poor mud displacement is cited as a prime factor in these studies. Wilson's work further details the phenomena of fluid density stratification in deviated wellbores and the resultant by-passing of drilling mud during cement placement. By-passing of less dense drilling fluid by the more dense cement creates uncemented intervals or mud channels that effectively destroy zonal isolation. The angle of inclination is measured with respect to the vertical, is illustrated in one of the publications which are incorporated by reference for any details omitted herein in the interest of brevity, and which may be in the range of from 55 degrees to 90 degrees, more particularly about 85 degrees to 90 degrees.

Laboratory modeling of cement displacement mechanics in the wellbore by numerous researchers has demonstrated that wellbore fluids will segregate according to density. The more dense fluids will seek the bottom of the wellbore and the less dense fluids will seek the top. Due to this well-recognized phenomena, it is generally recommended that each successive displacement fluid, i.e., spacer and cement be at least two pounds per gallon greater density than the displaced fluid, i.e., mud and spacer. This practice has been demonstrated to be particularly effective in vertical displacements. However, a single fluid of greater density does not effectively displace another fluid in high angle or horizontal wellbores, i.e., greater than 55 degrees deviation from the vertical.

In a deviated wellbore interval, gravitational separation of more dense cements from the other wellbore fluids can leave pockets of the less dense, non-cementitious fluids. As the angle of inclination, or deviation, increases so does the potential for entrapment of these

fluids along the top sides of the annulus and as a result there is left in place a pathway for zonal communication. Expensive and often unsuccessful remedial operations are generally required.

The development of a free water channel along the top side of the annulus is also well documented in the literature on cementing deviated wellbores. This phenomena was first described in SPE 8958 W.W. Webster and J.V. Eikerts and has been confirmed in numerous subsequent investigations. These studies have shown that as the angle of inclination increases, so does the extent and rate of development of the free water channel. The existence of this channel effectively destroys zonal isolation.

The discussion of the published articles referred to herein is incorporated herein by reference as indication of a state of the art and for any details that are omitted herefrom.

SUMMARY OF THE INVENTION

The present invention provides methods of cementing downhole in a wellbore penetrating subterranean formations, particularly at high deviated wells where it is deviated more than 55 degrees, to achieve substantially complete zonal isolation through improved displacement of non-cementitious fluids.

In accordance with one embodiment of this invention, there is provided a method of cementing downhole in wells penetrating subterranean formations and in highly deviated wells which includes flowing into the well, to be left in situ, a plurality of cementitious slurries, at least one of which is lighter than the drilling fluid within the wellbore, particularly in deviated wells from 55 to 90 degrees and which form a deviated or horizontal length of a hundred feet, or more.

In accordance with another embodiment of this invention, there is provided a method of cementing highly deviated wells, such as horizontal wells, which includes a

cement slurry that incorporates low density, fly ash or borosilicate micro-spheres for the purpose of free water control.

The low specific gravity (s.g.) of the hollow micro-spheres allows them to migrate upwardly in the aqueous cement suspension. The 0.37 - 0.9 s.g. of the micro-spheres is sufficiently lower than the 1.0 - 1.03 s.g. of the cement mix water to induce this upward migration. The concentration of micro-spheres along the "high" side of the wellbore assures cementitious material will remain in this critical area.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a cross-section of a horizontal portion of a well which has been cemented in a conventional manner.

Figure 2 is a cross-section of a horizontal portion of a well which has been cemented in accordance with the process of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figure 1, there is disclosed a horizontal portion of a well 21 formed through subsurface formations 23A, 23B, etc. which has been cemented with 15.8 ppg (pounds per gallon) conventional cement 25, with the use of 11.0 ppg ARCO spacer fluid 27 between the cement 25 and 10.0 ppg drilling mud 29. The upper end of the well is on the left, viewing the drawing. A production tube or casing is shown at 31. In the cementing process the spacer 27 and cement 25, separated by a plug (not shown), are injected down the tube 31 through an up-jet shoe (not shown) which then flows to the left. The plug will rupture at the up-jet shoe. In Figure 1, trapped mud is shown at 29T.

In this invention, the less dense cement slurry will displace the low density drilling fluid from the top of the well section, whereas the more dense cement slurry will flow along the bottom of the horizontal section of the well.

Specifically, the more dense cement slurry flows to the bottom of the section of the well and cements the casing along the bottom thereof, and effectively displaces the less dense fluids from the bottom of the deviated annulus.

As a result of bracketing the drilling fluids density with two or more cement densities, the drilling fluid and cement spacer are effectively "wedged" or displaced from the horizontal wellbore interval leaving only cementious fluids.

Best results are obtained by the method of this invention in which a plurality of cement slurries are run and take their respective places in the horizontal section of the wellbore hole to provide no residual drilling fluid channels along the upper portion of the cemented annulus.

Use of this invention increases displacement efficiency in these highly deviated wellbores where a truly turbulent flow cement slurry is not a viable alternative.

In the upper portion of the horizontal section of the borehole, lower specific gravities of cement slurries are employed, for example, even lower than that of the drilling fluid that was employed in drilling the well.

A low density cement in the form of a foamed cement slurry, or a cement slurry employing low density micro-spheres will be emplaced by injecting a slug of from 5 to 95 percent by volume of the combined cement volume at a density less than that of drilling fluid. For example, densities on the order of 8.0 to 12.0 ppg are frequently employed. This is ordinarily followed with more dense cement slurry which will run along the bottom of the casing and will join with the less dense cement slurry to form a completed annular cement sheath when left in the well at the desired location.

While the use of a cement slurry foamed with nitrogen or air, or a low density micro-sphere type slurry to form a less dense cement slurry has been described, at least implicitly hereinbefore, a more dense cement slurry

may be formed by adjusting water/cement ratios or incorporating other density adjusting materials in accordance with conventional technology. The more dense cement will form a more impermeable mass. It will join with the less dense cement slurry to set up in situ when left at a desired location in the well. The less dense cement slurry may use fumed silica, fly ash and borosilicate microspheres or entrained gases; i.e., N_2 to achieve the desired cement density and thus prevent residual drilling fluid channels along the upper portion of the wellbore. The joinder of the cementious slurries provides zonal isolation.

The more dense cement slurry may form the remainder of the cement slurry if only two slurries are employed.

Expressed otherwise, if 10 to 90 percent of the low density cement slurry is employed, then 90 to 10 percent of the more dense cement slurry may be employed to join with the less dense cement slurry and provide complete zonal isolation and good bonding.

If, on the other hand, a greater number of cement slurries are employed, then the proportion of each may be varied responsive to desired design criteria. In the case of foam cement the foam cement density can be smoothly varied across the full density range by gradually decreasing or increasing the gas injection rate. The design criteria can be effected by simulating in a computer environment a plurality of slurries of respective densities to get the desired result. It is imperative that the following criteria be observed.

The well must have a highly deviated section in excess of 55 degrees. The publications show that the density separation becomes more severe when above about 60 degrees angle of inclination is experienced. It has been found by the invention herein that the problem of density separation becomes particularly severe in wells as angles approach 85 - 95, 100 degrees, or substantially horizontal.

If desired, spacer fluids may be employed herein as delineated in the prior art. The spacer fluids simply form a barrier between the drilling fluid and the cement so as to reduce the critical sensitivity of the rheological factors of the cement slurry contacting the drilling fluid. By preventing the mud from contaminating the cement, these spacer fluids minimize the tendency of drilling fluid dispersant to adversely affect or prolong cement strength development. These factors are all well known.

Figure 2 illustrates the same well of Figure 1, but a 9.8 ppg lightweight cement 35 is used between the cement 25 and the spacer 27. As shown, the lightweight cement 35 displaces and prevents trapped mud at the top insuring that the well is cemented completely around the tube 31 and the walls of the well in the section shown. A plug (not shown) may be located between the cement 25 and the cement 35 while they are injected through the tube 31 for separation purposes.

An example of this invention is provided for cementing of the Yowlume 16X-4 Well in California.

A similar cement design was used in the Kuparuk River Basin (Alaska) Well No. 1R/21. Both the Yowlume 16X-4 Well and the Kuparuk 1R/21 Well were noted for excellent cement. Well 1R/21, provided a cement bond log that was superior to that of adjacent vertical and less deviated wells.

EXAMPLE I

In the Yowlume 16X-4 Well cementation, about 100 barrels (42 U.S. gallons per barrel) of 9.0 ppg cement were used to displace a 10.4 ppg mud from the high side of a 3700' horizontal section of this, 15,300 ft. measured depth or 11,255 ft. true vertical depth, deviated wellbore. A greater volume of 13.5 ppg cement was used to effectively displace the vertical and the low side of the high angle intervals of the wellbore annulus. The low density or 9.0 ppg cement was formed with the use of fumed silica and fly ash micro-spheres; more specifically: API Class C cement, 100% micro-spheres, 10% fumed silica, 0.75% dispersant, 0.75% fluid loss additive, .057% retarder, 0.2% nonionic surfactant and 140% water, all concentrations being based on the starting weight of dry Portland cement. The cementation of this well was successful, an excellent cement bond was secured, and no remedial cementation was needed.

Once a base formulation is determined, additional additives such as dispersants, or fluid loss additives, retarders, accelerators and the like, can be added in much the way as they are in conventional cement slurry systems. The above cement design develops 1000 to 2000 PSI in 24 hours, depending on bottomhole temperature.

As the slurry density increases above 10 ppg, the compressive strength properties improve even more rapidly. Also, very low density (0.37 - 0.43 s.g.) borosilicate spheres can be used in place of the ceramic spheres to produce further slurry density reductions or greater strength/density relationships.

As downhole hydrostatic pressures increase, particularly above 4000 psi, a percentage of the fly ash or borosilicate glass micro-spheres are crushed (implode). This results in an increase in cement slurry density. In those wells where the density increase is too great and cannot be effectively addressed by increased micro-sphere concentrations, high strength borosilicate micro-spheres can be employed. The high strength (0.7 s.g.) borosilicate

spheres can extend the hydrostate pressure range of these cement designs to beyond 10,000 psi.

EXAMPLE II

The following examples are cement slurries that have been employed to give about 9 pounds per gallon (ppg) cement slurry density.

Basic Designs: 9.0 ppg (when percentages are indicated herein, they are percentages by weight - % by wt)

Type I Cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silica + 132.5% Water
PV=97 YP=37 Compressive Strength: 700 PSI @ 24 hrs. @ 190 degrees F. BHST

Type I Cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silica + 0.6% Retarder + 112.5% Water
PV=118 YP=6 Thickening Time: 2 hrs. 56 mins. @ 190 degrees F. BHCT

Type III Cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silica + 132.5% Water
PV=63 YP=8 Compressive Strength 875 PSI @ 24 hrs. @ 190 degrees F. BHST

Type III Cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silica + 116.5% Water
PV=68 YP=48 Compressive Strength: 1200 PSI @ 24 hrs. @ 190 degrees F. BHST

Type I Cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silica + 0.5% Dispersant + 0.6% Fluid Loss Additive + 0.5% Retarder + 140% Water
PV=102 YP=30

Class G cement + 100% Fly Ash Micro-Spheres + 10% Fumed Silicate 1% Dispersant + 2 gal. Styrene Butadiene Latex/sk of cement (gal/sk) + 0.22 gal/sk Surfactant + 0.05 gal/sk defoamer & 013% Retarder + 12.39 gal/sk Fresh Water

PV=98 YP=-4 Compressive Strength: 700 psi @ 48 hrs. @ 145 degrees F. BHST

When particulates, such as micro-spheres, less dense than the cement are added to the cement slurry, they will preferentially float or migrate above and in the cement free water. This provides a uniform cylindrical suspension of cementitious solids that will harden without the void (free water channel) common to conventional cements that are cured at deviated angles. The fly ash or borosilicate glass micro-spheres serve as a reactive "place holder". they maintain a solid packing in the top of the wellbore or annulus and react with the calcium rich mix water to form a cementitious solid or pozzolan cement. This protection can be further enhanced with the use of fumed silica to decrease mix water separation and reduce the permeability of the micro-sphere cement.

Low density micro-spheres, such as those formed from pozzolan or borosilicate glass, or ceramic, have a density or specific gravity (s.g.) less than the 1.0-1.03 s.g. of the cement mix water. Thus, the less dense spheres (0.37-0.9 s.g.) will form a cementitious material along the top of the horizontal sections and will prevent the free water channels from forming. Free water channels can destroy zonal isolation.

The use of a low density cement slurry incorporating micro-spheres is acknowledgedly old in cementing wells penetrating subterranean formations, but not for the prevention of water channels in horizontal or deviated wellbores.

Cement slurries with densities ranging from 16.0 - 8.5 ppg are being developed for field implementation of this technology. The quantity of micro-spheres may range from as little as 5% by weight of cement to as much as 150%. These designs may or may not incorporate fumed silica or other generally applied cement admixes.

What is claimed is:

Claims:

1. In a method of cementing downhole in a wellbore in which a drilling fluid will have been used to drill the well, at least a portion or which is deviated more than a 55 degree angle of inclination; the improvement comprising:

a. emplacing at a desired depth in the well a plurality of cement slurries, at least one of which is less dense than the drilling fluid employed to drill the well or current wellbore fluid, and

b. allowing the cement to set up in the well to provide zonal isolation and bonding of equipment in the wellbore.

2. The method of Claim 1 wherein at least one of said cement slurries has a density less than 12 pounds per gallon and at least one of said cement slurries has a density greater than 12 pounds per gallon.

3. An improvement in a method for cementing wells penetrating subterranean formation; and, particularly in deviated or horizontal sections of a wellbore, characterized by the steps of:

a. flowing a micro-sphere laden cement slurry into the well; and

b. leaving the cement slurry in the well to bond the equipment in the well and provide improved zonal isolation by eliminating development of free water channels.

4. The improved method of Claim 3 wherein said cement slurries are formed with micro-spheres selected from the class consisting of fly ash or borosilicate glass spheres that are hollow, so as to rise to the top, their specific gravity range being in the range of 0.3 - 1.0.

5. The improved method of Claim 4 wherein about 5 - 50% fumed silica is employed in the cement.

6. The improved method of Claim 3 wherein said micro-sphere laden cement reduces slurry density while providing excellent cementitious properties, provides excellent slurry properties for ease in mixing and displacement, creates a slurry that can be designed to have upward migration of cementitious solids in a horizontal or deviated section of a well to eliminate the high side free water channels, and improves success rates wherein the cement slurry will set to provide a compressive strength in excess of 1000 psi.

7. The improved method of Claim 3 wherein said micro-sphere laden cement reduces slurry density while it will set to provide a compressive strength in excess of 500 psi.

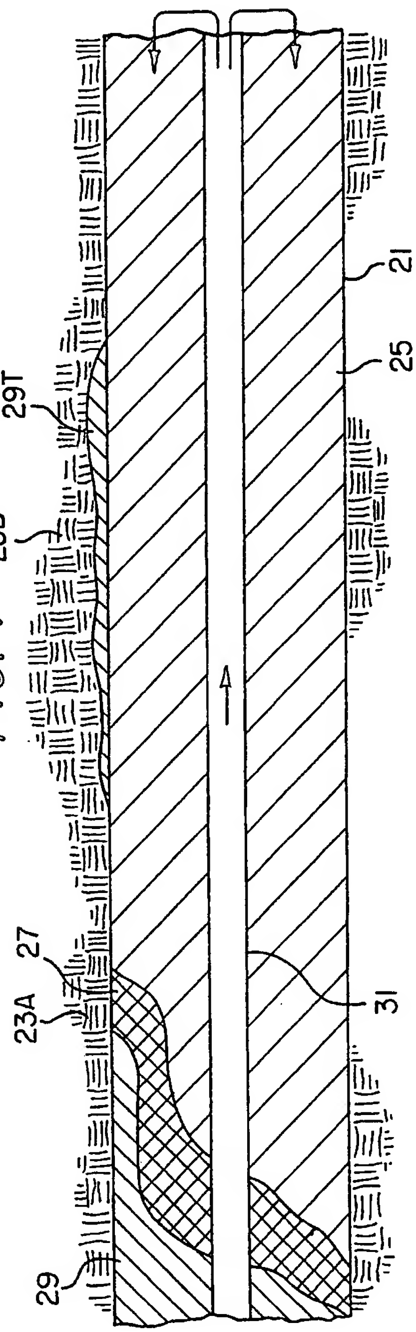

FIG. 1

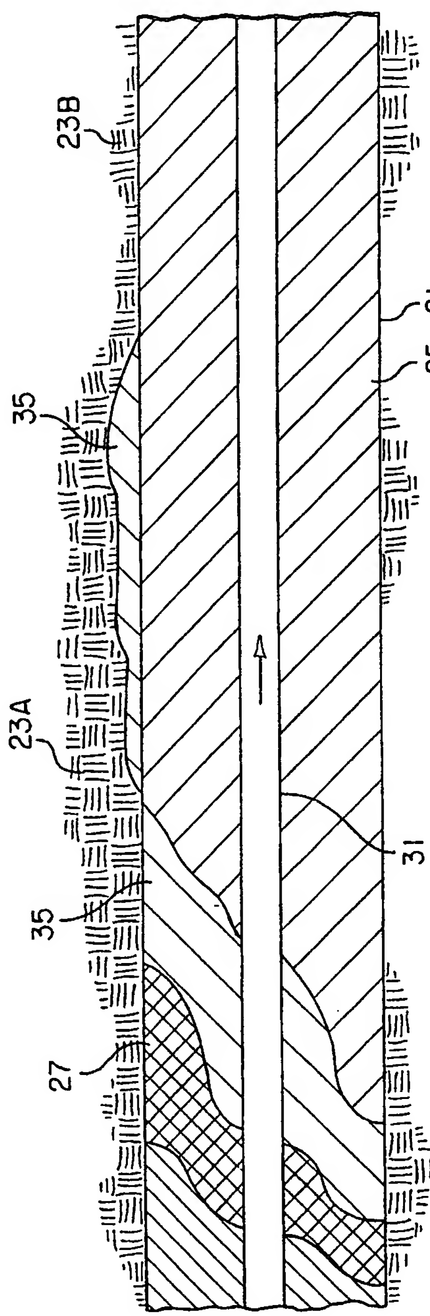

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/09437

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :E21B 33/14
US CL :166/285,50,250,292
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/293,295,291

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A, 3,804,058 (Messenger) 16 April 1974, see col. 2, lines 10-15 and 44-66.	3 and 4
A	US,A, 3,669,701 (Biederman, Jr.) 13 June 1972 (Fig. 1 and col. 3, lines 45 to col. 4, line 31).	1-7
A	US,A, 3,887,385 (Quist, et al.) 03 June 1975, (col. 2, lines 16-38).	1
A	US,A, 3,526,280 (Aulick) 01 September 1970. (Figs. 1-4, col. 1, lines 45-56).	1
A	US,A, 2,206,389 (Cannon) 02 July 1940 (Fig. 1-3)	1

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search 09 MARCH 1993	Date of mailing of the international search report 17 MAR 1993
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/09437

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A, 2,848,051 (Williams) 19 August 1958 (Fig. 1-3)	1
A	US,A, 3,376,146 (Mitchell) 02 April 1968 (col. 2, lines 53-70).	1
A	US,A, 4,530,402 (Smith, et al.) 23 July 1985 (col. 4, lines 60-col. 5 line 6).	3,4